Preprint
UCRL-JC-154028

Optical CDMA (O-CDMA) Technology Demonstrator (TD) for 2D Codes

A. J. Mendez, V. J. Hernandez, C. V. Bennett,
W. J. Lennon,and R. M. Gagliardi

This article was submitted to the
IEEE Laser and Electo Optical Society (LEOS) annual meeting
26-30 October 2003

U.S. Department of Energy
Lawrence
Livermore
National
Laboratory

October 26, 2003

Optical CDMA (O-CDMA) Technology Demonstrator (TD) for 2D Codes

Antonio J. Mendez
Mendez R&D Associates, P.O. Box 2756, El Segundo, CA 90245, Phone: (310) 640-0497, MendezRDA@AOL.com

Vincent J. Hernandez*[a], Corey V. Bennett*, and William J. Lennon*,
**Lawrence Livermore National Laboratory (LLNL), P.O. Box 808, L-229, Livermore, CA 94551;*
[a]University of California at Davis, Department of ECE, Davis, CA 95616

Robert M. Gagliardi
Department of EE-Systems, University of Southern California, Los Angeles, CA 90089-2565

Abstract: A TD based on wavelength/time codes, configured to multiplex and transmit 32 asynchronous Gigabit Ethernet data flows (GbE over O-CDMA), is described. The TD is user and data rate scalable.

1.0 Introduction

O-CDMA technology is interesting for local area and access networks because of its ability to aggregate (multiplex) and broadcast asynchronous, concurrent, bursty data flows without requiring optical/electrical/optical (O/E/O) conversion [1,2]. More recently, O-CDMA has also been considered as an enabler for an all-optical packet switch technique [3,4]. Among the types of O-CDMA codes, 2D codes are receiving increasingly more attention because of their superior spectral efficiency (S.E.) compared to direct sequence codes, especially if intensity modulation/direct detection (IM/DD) schemes are used [5,6,7]. The type of O-CDMA 2D codes used in the TD are based on folded optimum Golomb rulers [8]. This method of generating 2D optical orthogonal codes (OOCs) permits the designer much flexibility in tailoring them to be easily implemented and reconfigured while using only available (e.g., DWDM) technologies.

2.0 O-CDMA Technology Demonstrator (TD)

The TD is based on wavelength/time (W/T) matrix codes. The code construction produces more codes (32) than constituent wavelengths (8), so the coding is acting as a wavelength multiplier. To reduce costs and complexity, a "central office" generates an Encodable Carrier (EC) that is distributed to the users by means of a tree topology network. The EC is a time-frequency comb with 100 ps (the chip time) RZ pulses, a repetition frequency of 1.25 GHz, and eight wavelengths (C35-C42 on the ITU grid). Using the first four of the eight chips in the bit for the coding gives a 50% guard-time (GT) to avoid inter-symbol interference, ISI [8]. Users encode the EC with their code and impress NRZ GbE data on the encoded EC. Encoded data is broadcast to the other users by means of a 32x32 star coupler or linear bus. Encoders/decoders are based on AWGs, 1x4 couplers, and delay-line arrays. The TD is currently configured for 32 GbE users but is scalable to 64-80 users (by redesigning the codes) and/or to higher data rates (by scaling the RZ pulse, its repetition rate, and the delay-lines). The TD architecture is shown in **Figure 1**.

3.0 Set-up and Preliminary Results

Figure 2 shows the TD installed in a 19" rack. The 48 1x4 couplers are in four 2U enclosures; the 32x32 star coupler is in a 1U enclosure; and the 18 AWGs are in an 8U enclosure. The TD architecture defines the wiring diagram among these enclosures and active components such as the multi-wavelength source. The computed and measured output of decoder M9 with 0 to 3 interferers are shown, respectively, in **Figure 3** and **Figure 4**. The decoded signal is clearly visible over the multi-access interference, MAI (which is seen building up with the number of interferers). Analyses, Excel spreadsheet simulations, and R-Soft LinkSim simulations all indicate that the visibility of the signal over the MAI as shown in Fig. 4 will be good until 16 concurrent users (using 50% GT), giving an S.E of 0.25 bit/s/Hz [8]. For >16 users, MAI suppression (e.g., optical hard-limiting, OHL) is required. Earlier results show that OHL is sufficient to support at least 24 concurrent users, an S.E. of 0.37 bit/s/Hz [8]. The O-CDMA TD is intended to explore and extend the boundaries of O-CDMA in terms of asynchronous users and associated data rates.

Acknowledgments
This effort was supported in part by U.S. Department of Energy SBIR Phase II Grant ER83277 and performed under the auspices of the U.S. Department of Energy by the University of California LLNL under contract No. W-7405-Eng-48 and a subcontract to ER83277. The collaboration between MRDA and LLNL was carried out under Cooperative Research and Development Agreement TC-2051-02.

References

[1] P. R. Prucnal, M. A. Santoro, and T. R. Fan, "Spread spectrum fiber-optic local area network using optical processing", J. Lightwave Tech., vol. LT-4, pp. 547-554 (1986).
[2] T. Pfeiffer, B. Deppisch, M. Witte, and R. Heidemann, "Optical CDMA Transmission for Robust Realization of Complex and Flexible Multiple Access Networks", Conf. Proc. OFC'99, WM51, p. 344.
[3] N. Wada, H. Harai, and F. Kubota, "40 Gb/s Interface, Optical Code Based Photonic Packet Switch Prototype", Conf. Proc. OFC'03, FS7, p. 801.
[4] D. Gurkan, S. Kumar, A. Sahin, A. Willner, K. Parameswaran, M. Fejer, D. Starodubov, J. Bannister, P. Kamath, and J. Touch, "All-Optical Wavelength and Time 2-D Code Converter for Dynamically-Reconfigurable O-CDMA Networks using a PPLN Waveguide", Conf. Proc. OFC'03, FD6, p. 654.
[5] E. Park, A. J. Mendez, and E. Garmire,"Temporal/spatial optical CDMA networks-design, demonstration, and comparison with temporal networks", IEEE Photon. Tech. Lett., Vol. 4, p.1160-1162 (1992).
[6] H. Fathallah. L. A. Rusch, and S. LaRochelle, "Passive Optical Fast Frequency-hop CDMA Communications System", IEEE/OSA J. Lightwave Tech. vol. 17, pp. 397-405 (1999).
[7] R. M. H. Kim, L. R. Chen, and J. Bajcsy, "Design and Performance of 2D Codes for Wavelength-Time Optical CDMA", IEEE Photon. Tech. Lett., vol. 14, pp. 714-716 (2002).
[8] A. J. Mendez, R. M. Gagliardi, V. J. Hernandez, C. V. Bennett, and W. J. Lennon, "Design and Performance Analysis of Wavelength/Time (W/T) Matrix Codes for Optical CDMA", accepted for publication, IEEE/OSA J. Lightwave Technol., Special Issue on Optical Networks, Vol. 21, TBD, Dec., 2003.

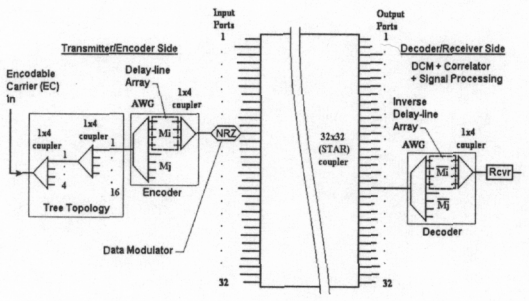

Figure 1. TD Top Level Architecture.

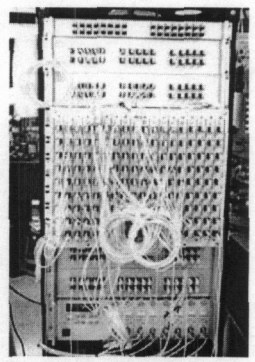

Figure 2. TD Set-up.

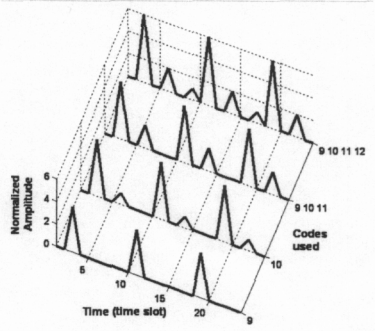

Figure 3. Computed Signal+MAI (0-3 Interferers).

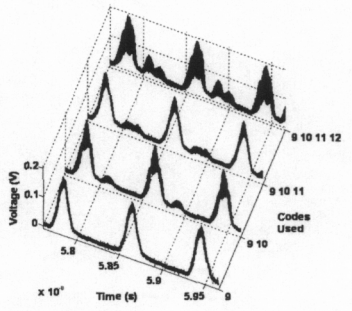

Figure 4. Measured Signal+MAI (0-3 Interferers).